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Art. XIII.—*The Building Stones of Victoria.*

Part I.—The Sandstones.

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(With Plates XXXIII.-XXXVI).

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INTRODUCTION.

Although Victoria is a country rich in various mineral deposits, it has not up to the present yielded a sandstone with properties which have rendered its adoption to any extent for building purposes. The want of a good cheap Victorian freestone is at present severely felt by Melbourne architects, and although many stones have been tried at different times in Melbourne, one having the combination of good weathering and economical dressing properties has not been obtained.

For many years thorough investigations into the weathering properties of building stones have been carried out in America and Germany, but in Victoria very little appears to have been done in this direction.

In the early sixties J. G. Knight[1] carried out investigations on several Australian stones then used; while some of his results still hold, much of it, more especially the chemical portion, is almost valueless. In 1873 a Board was appointed to examine and report on suitable stone for the erection of the Houses of Parliament; their report was submitted early in 1879, and then, as now, the difficulty of finding a cheap and good weathering stone was very pronounced. The stone eventually chosen for the Houses of Parliament was that from the Grampian quarries, 17 miles north-west from Stawell. It is the

1 Australian Building Stones, 1864.

sandstone with the best weathering properties which Victoria has produced, but on account of its cost in dressing, is in most cases prohibitive to the private individual.

In the early building days of Melbourne, Tasmanian sandstones were extensively used, and at the present time, in buildings other than public ones, little else than Sydney stone is used, while all along Victorian sandstones have been adopted only to a small extent.

Of recent years the methods of testing stones for building purposes have been greatly improved, and since the advent of the microscope much more has been learnt about the constitution and the minerals in the stones, so that by its use in conjunction with the other tests, much more can be concluded from laboratory experiments than was the case previously.

In view of all this, it was felt that an investigation on a thoroughly scientific basis would yield results of value both to the quarry owner and the architect, and as a result this work was entered upon.

Sandstones.

The following Victorian sandstones have been dealt with:—

1. Stawell.
2. Dunkeld.
3. Barrabool Hills.
4. Apollo Bay.
5. Bacchus Marsh.
6. Darley.
7. Egerton—both fine and coarse.
8. Greendale.

GENERAL DESCRIPTION.

Stawell Stone.

This is a fine, even grained, white sandstone, quarried at the foot of the Grampian Ranges, 17 miles north-west of Stawell. It is a very hard and compact stone, probably of carboniferous age, shows very little bedding in the fresh state, and is remarkably free from ironstaining.

In places the stone has abundant segregations and veins of secondary silica termed "flints" by the masons. The initial hardness of the stone, together with the presence of these flints, renders the stone a very expensive one to dress. The beds, which are thick, dip into the hillside at about 45 degrees in a westerly direction. Stones of any size in reason are obtainable, and the quality seems fairly uniform throughout the quarry.

Current bedding exists in the stone to a large extent, and although it does not appear in the freshly quarried or dressed stone an examination of the weathered material detects it, owing to the slight inequality in hardness of the different layers. A small quarry has been opened up by Robson and Gray a little to the south of the main quarry, but the stone therein is more ironstained than in the large quarry, and some difficulty has been experienced in obtaining a good "back." This so-called "brown stone" is finding a ready sale for pitcher-making, and is being extensively used in many places for this purpose.

The stone was used in the Stawell Town Hall when the quarries were first opened up, but much of the surface material was differentially iron-stained. For this reason alone, and not on account of its weathering away, the stone in the Town Hall was painted in after years. The Stawell Court House, built in 1879, is a splendid example of the weathering properties of this stone, and to-day looks almost as fresh as newly-quarried stone, being especially clean looking in contrast with the dirty appearance the stone takes on in Melbourne after a time, due to the deposition of sooty and tarry material.

Buildings of this stone in Melbourne are Parliament House, the Crown Solicitor's Office, the recent additions to the National Museum, the upper portions and recent additions to the General Post Office and Town Hall.

Dunkeld Stone.

This is a fine even-grained sandstone, with a light brownish tint, and well defined bedding planes. It is quarried on the slopes of Mt. Abrupt, three miles from Dunkeld, at the southern end of the Grampian Range, about 40 miles due south of the Stawell quarries.

This stone forms part of the same series of sandstones as the Stawell stone, and is probably of carboniferous age.

The quarry, although opened up in 1860, has not been extensively worked, and a lot of dead work has been done owing to bad iron-staining and to a large fault. The beds dip west, at about fifteen degrees into the hill, away from the quarry, which is situated on the opposite side of the Wannon River from Dunkeld; with the result that the cost with the present system of carriage is increased. The cost of dressing this stone is about 20 per cent. less than Stawell stone, but it has not the uniform colour of the latter. Up to the present none of the troublesome "flints" of the Stawell stone have been encountered, but "sand-balls," generally along the bedding planes, are met with

Occasionally, hard, flinty bands up to an inch or two in thickness and generally more ironstained than the surrounding stone are met with, but these can be avoided. A marked defect of this stone is the current or false bedding, which becomes most pronounced on weathering, and may be seen very well in the stone used in the recent additions to the Women's Hospital, Carlton. Between the layers a fine argillaceous powder is present, which falls away readily on weathering. This, together with the differential ironstaining of the layers, gives the stone after being in a building a very short time a bad appearance. This stone has not been used to any extent, but may be seen in the Hospital mentioned above, and in the Presbyterian Church, Hamilton.

Barrabool Hills Stone.

This is a fine, even-grained sandstone, of a light green-brown colour. It is quarried in the vicinity of Ceres, among the Barrabool Hills, near Geelong. It is of Jurassic age, and forms part of the widely distributed series of lake sandstones laid down during Jurassic times. The stone is of fresh water origin, and is made up largely of igneous material containing carbonaceous inclusions in the way of leaves and stems of ferns and other plants.

Its weathering properties are variable for different quarries, but the samples investigated were obtained from McCann's

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1 Krausé. Progress Report, No. 1, Geol. Survey Vict., p. 130.

quarry at Ceres, and which is generally regarded as producing the best stone.

The bedding is difficult to discern when freshly dressed, with the result that in many of the older buildings it has been used with the bedding vertical, thus leading of course to disastrous results. The stone is fairly uniform in colour, though gradations to the bluish-grey colour of the stone in its unaltered state are discernible. Bands of grit occur here and there through the stone, which is almost horizontally bedded in the above quarry.

This stone, which is a sóft one, and dresses easily, though rather treacherous, has been used extensively in Geelong and other places. When rough dressed it weathers better than when smooth-dressed, as in the latter case it has a tendency to flake off on weathering, due to a disturbance of the particles near the surface of the stone during dressing operations.

An examination of the Geelong structures of this stone gives a good idea of its weathering properties, as some of them have been erected for about fifty years—e.g., the Art Gallery in Moorabool-street. The stone breaks away at the corners, and flakes along the edge, more especially if in a damp situation, with the result that these older buildings have to be continually repaired and patched with cement.

The stones crack easily, especially those over the windows, for quite large stones which one would expect to stand the pressure, easily develop dangerous cracks.

In other stones wind erosion effects are most pronounced if the stone is at all gritty, the harder parts standing out like pimples. The Old Police Court, at the corner of Russell and Latrobe streets, Melbourne, was built with this stone in 1842, and here one sees how stone may decay, for nearly all the stones are in a most rotten condition, and many of them could be crumbled in the hand. Other structures in Melbourne of this stone are St. Paul's Cathedral, which is showing very evident signs of decay in many places; Scots' Church, the Working Men's College, Ormond College, and the Biology and Medical Schools at the University. In many of the buildings of this stone in Melbourne the gables come away from the main structure to the extent of one or two inches after a time; some light may be thrown on this movement by the results in the following tests on the stone.

Apollo Bay Stone.

This is similar to the Barrabool Hills stone, with the exception that it is fresher and has a bluish-grey colour. It is of Jurassic age, and outcrops all along the coast in the neighbourhood of Apollo Bay, the quarry being situated right on the coast. The overburden is small, and even just below the capping the stone is remarkably fresh. Some stone quarried about fifteen years and which has been exposed to all weathers, is in a good condition, having weathered excellently. There is a fading in colour, but this is very little more pronounced than that which takes place after three or four years' exposure.

Blocks of any size within reason are obtainable, and the stone has the advantage of working very freely and dressing well.

It has not been used to any extent, but may be seen in the Cape Otway lighthouse, built many years ago, and also in the recently built Windsor Exchange.

Bacchus Marsh Stone.

This is a soft, even-grained sandstone of light brown colour. It is not at all a compact stone, and is unevenly ironstained. It is quarried at Bald Hill, about three miles from Bacchus Marsh, and has been used largely in that district. The stone is the well-known Bacchus Marsh sandstone of Permo-Carboniferous age. An examination of the quarry shows that it is anything but uniform in hardness, and also in quarrying a large amount of waste material is produced. This stone has been used in the Treasury Building, Spring-street, Melbourne, but has not stood at all well, many of the blocks being so rotten as to cause their replacement some little time ago. Several structures of this stone in Bacchus Marsh exist, but in every case, with the exception of the Church of England, the stone is in a very bad state. In the latter building the stones are rough dressed, but very uneven in colour.

Darley Stone.

This is a very soft, fine-grained sandstone, of a light buff colour. The quarries are situated about six miles from Bacchus Marsh, on Goodman's Creek, near Coimaidai. Several small quarries exist, but in all the stone is of a very poor quality, weathering away rapidly, as shown by the blocks about the quarries. The samples on which these investigations were carried out were obtained from Cosgrove's quarry. This stone has been used in the Parliamentary Library—lower portion—and in the Treasury, to replace the weathered Bacchus Marsh stone, but in both cases it has crumbled away badly.

Egerton Stone.

Fine-grained.—This is a fine-grained white sandstone of a very clean appearance, and dresses well. It is not quite uniform in hardness, due to the presence of thin hard layers here and there through the stone, and is slightly discoloured in parts by ironstaining.

Coarse-grained.—This is considerably coarser than the above stone, but also dresses well and works easily. It exhibits a well-defined bedding plane, due to slight differences in the size of the grains in the different layers. In appearance it very much resembles the freshly quarried Sydney sandstone, is very friable, and must be regarded as a soft sandstone.

Both the stones are obtained from the same deposit on the east bank of the Moorabool River, near Egerton. The deposits —which consist of sandstones of Ordovician age—are tilted almost vertically, and strike north and south. One can obtain every gradation, from the fine to the coarse stone, but at one point there is a good thickness of fine, compact stone, of uniform grain and colour. This patch was worked a little, some sixty years ago, to obtain material for a house in the neighbourhood, and the weathering of the stone in this structure is excellent.

Greendale Stone.

This is a coarse-grained, light-coloured sandstone of good appearance, and is made up of sand grains and occasional pale green patches of shaley material in lenticular masses, bound together by a whitish cementing material uniformly speckled with iron oxide. The stone is friable, and works very easily, but needs care in dressing. From samples the stone seems uniform in hardness and colouring, but the author has not visited the quarry, which is a few miles from Ballan, and nothing is known of its weathering properties in buildings.

It should be mentioned that all these stones, after being quarried or dressed, get a thin skin or coating of harder material all over them. This is more pronounced in the Bacchus Marsh, Darley, Egerton and Greendale stones than in the others, and is produced by the percolation of the "sap" water to the surface, and there evaporating, leaves the dissolved material in the form of a thin hard skin.

METHODS OF TESTING.

The determination of the actual qualities of a stone, good or bad, by laboratory tests, is exceedingly difficult. As the object of many of the tests conducted in the laboratory is to produce the same effects in a few days as are produced in as many or more years under normal weathering conditions, a great deal depends on the methods adopted. However, if all the stones are uniformly treated by these methods, which must necessarily be arbitrary, one obtains at least comparative results, and the relation which one stone bears to another is derived. Stones of known weathering properties, either good or bad, may form part of the series uniformly treated, and the relations which the unknown stones bear to the known ones will give a fairly accurate idea of the durability of the former. Unfortunately, the methods adopted in the laboratory are not the same in all countries, although steps are being taken by an International Congress to fix standard tests.

In the main the tests applied by the author are those followed by G. P. Merrill,[1] of Washington, U.S.A.

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1 Merrill. "Stones for Building and Decoration."

TESTS.

The following investigations were carried out on all the sandstones:—

1. To ascertain the specific gravity.
2. To ascertain the resistance to crushing.
3. To ascertain the absorptive powers.
4. To ascertain the resistance to corrosion.
5. To ascertain the resistance to mineral acids.
6. Microscopical examination.
7. Chemical analysis.

There are several other tests regularly conducted on building stones, but these were not included for various reasons. While a knowledge of the resistance to freezing is of supreme importance in many places, fortunately in Melbourne it is not so, as this city is almost free from frost, also the difficulty of obtaining anything like reliable results is very great.

The resistance of a stone to abrasion by wind-blown particles is rather important in Melbourne, but the difficulty of getting reliable results and the lack of opportunity for carrying out the test led to its non-inclusion.

1.—*Specific Gravity.*

Pieces of the stones were carefully dried at 110 degrees C., weighed in air when cold, and then suspended in water and there weighed. From the two weights the specific gravity was determined.

The specific gravity is of value in indicating which stones are liable to be the most absorptive, for with stones of the same mineral composition the one with the highest specific gravity is generally the least absorptive and so the most durable.

Several determinations were carried out on each stone, and the results appended below are the means of these. From the specific gravities the weight per cubic foot of these stones has been determined. With porous stones like these sandstones, the determination of the true specific gravity is a matter of some little difficulty, especially in obtaining the correct weight of the stone when suspended in water.

The Sydney stone has been inserted for comparison.

TABLE OF SPECIFIC GRAVITIES AND WEIGHTS PER CUBIC FOOT.

Stone	Specific Gravity	Weight per Cubic Foot, in lbs.
Stawell	2.371	148
Dunkeld	2.324	145
Barrabool Hills	2.144	134
Apollo Bay	2.335	146
Bacchus Marsh	2.081	130
Darley	2.043	128
Egerton (fine)	2.114	132
Egerton (coarse)	2.039	128
Greendale	2.164	135
Sydney	2.303	144

Most of the stones are light. This is due to their high porosity as shown later on by their absorption values. The most compact one is that from Stawell, and it is also the least porous.

2.—*Resistance to Crushing.*

These compression tests have been carried out on the testing-machine at the Engineering School, University of Melbourne, by Mr. James Mann, and I am indebted to Acting-Professor Higgins for their inclusion here. This test is the one most commonly conducted on building stones, but its value lies more in giving an indication of the adherence of the particles in the stone, and so a measure of the stone's durability, than whether it is strong enough, as only in exceptional cases with ordinary building stones does the load approach the safety value. Most of these tests have been conducted on 3-inch cubes, or thereabouts, in the usual manner, and the Sydney sandstone is again inserted for comparison. Merrill[1] states that no fair comparison of the crushing strengths of stone can be made except between results obtained during a single series of tests. However, the values in the accompanying tables have all been obtained in a uniform manner by the same operator, and can reasonably be assumed to be fairly comparative amongst themselves.

1 Stones for Building and Decoration, p. 497.

A perusal of the tables shows that the stones with the best weathering properties are the most resistant to compression, and that probably the poorest building stone in the list—viz., the Darley, also has the lowest compression value.

The Stawell stone gives remarkably high results, exceeding those of many granites. The Apollo Bay stone gives a good value, and this seems quite in keeping with its resistance to weathering. The Sydney stone comes next, with the Dunkeld a little below it.

The Barrabool Hills stone gives a low value, and from the manner in which it weathers can be considered only a fair stone. With regard to both the Bacchus Marsh and Darley stones, both give very low values, quite consistent with their durability, as seen in Bacchus Marsh and in Melbourne.

The fine-grained Egerton stone value is fair, and from what is known the stone weathers well. The other values are low, but nothing is known of their weathering properties in buildings.

TABLE OF COMPRESSION TESTS.

Stone	Size of Cube in inches	Total strength in lbs.	Strength in lbs. per square inch
Stawell	3	101.300*	11.255
,,	2	70.200	17.550
,,	2	70.000	17.500
Dunkeld	3	50.750	5.640‡
,,	3	39.250	4.360‡
Barrabool Hills	3	29.670	3.297
,, ,,	3†	26.500	3.195
Apollo Bay	3	61.500	6.833
,,	3†	73.900	7.866
Bacchus Marsh	3	17.750	1.940
Darley	3	10.300	1.144
Egerton (fine)	3	38.600	4.288
Egerton (coarse)	3	18.300	2.033‡
,, ,,	3	27.300	3.033‡
Greendale	3	21.600	2.400
Sydney	3	66.300	7.366
,,	3	43.200	4.800

* Crack at 90.000 † Approx. ‡ Perp. to bed.

3.—*Absorption.*

This test is one of the most important, especially with sandstones, but the chemical and physical natures of the stone must be considered as well as the absorption in ascertaining its durability.

There are several methods of determining this factor, but the simplest one has been adopted—that of total immersion in water till the stone is thoroughly saturated.

Two-inch cubes, with faces smooth dressed, were used. These were first thoroughly dried, weighed, and then placed in wide glass beakers, covered with distilled water, and allowed to remain there for four days, which time was found sufficient for the complete saturation of all the stones treated. The cubes were then carefully removed, the surface water absorbed by blotting paper, and then weighed with the least possible delay. The increase in weight gives the amount of water absorbed. If this be multiplied by the specific gravity of the stone, it gives the bulk absorption, or the weight of stone which would occupy the same space as the absorbed water does, and so the porosity. In all cases several determinations were made, and in the accompanying table are the means of these values. There is a great variation in the absorption of the different stones, for the Bacchus Marsh is three times as porous as the Stawell stone. The Stawell and Dunkeld stones are the least porous by a considerable extent, while the others, with the exception of the Apollo Bay stone, may be considered high, more especially that from Bacchus Marsh. The freezing of absorbed water is a very large factor in the disintegration of stones, and as a rule the value of a sandstone is the inverse of its absorption.

In Melbourne, owing to its small amount of frost, these high absorptions are not of so much importance as they would be in less favourable climates, but it must be remembered that the more porous the stone the more accessible are its alterable constituents to the destroying elements. The Stawell value is low, but this is to be expected from the physical and chemical nature of the stone. The Dunkeld and Sydney percentages may be regarded as fair, while the Apollo Bay stone gives a rather high value. All the others are high, more especially the Bacchus Marsh value.

From a microscopical examination of thin sections of these sandstones, the relative absorbent values may be determined, particularly for the Bacchus Marsh, Darley, Egerton and Greendale stones, as the amount of water absorbed varies almost directly as the amount of fine-grained cementing matrix in the stones.

Unfortunately, the matrix is of an argillaceous character, so that the high absorptions of these stones especially, must be regarded as detrimental.

TABLE OF ABSORPTIONS IN PERCENTAGES.

Stone	Absorption by weight	Absorption by bulk
Stawell	2.38	5.64
Dunkeld	3.41	7.92
Barrabool Hills	7.68	16.46
Apollo Bay	4.49	10.48
Bacchus Marsh	8.70	18.10
Darley	7.40	15.12
Egerton (fine)	6.93	14.65
Egerton (coarse)	6.54	13.33
Greendale	7.74	16.75
Sydney	3.65	8.40

4.—*Resistance to Corrosion.*

The object of this test is to find out the effect on the stones, of water containing carbon-dioxide in solution. Carbon-dioxide occurs to the extent of about .04 per cent. in Melbourne air. Rain water, carrying it in solution, is capable of dissolving calcium, magnesium, and iron carbonates, so that any stones containing these are affected by it. Limestones of course are more severely acted on than other stones, but sandstones containing these minerals are also affected.

Two-inch cubes, smoothly dressed were thoroughly dried at 110 degrees C., cooled, weighed, and immersed in water, through which a current of washed carbon dioxide was passed continuously for three weeks. Precautions were adopted to keep a quantity of the gas in contact with the water, so that it was kept thoroughly saturated, and the water was changed every few days.

Along with the sandstones was placed a cube of Carrara marble for comparison.

At the end of the time the cubes were carefully removed, dried for many hours at 110 degrees C., and then weighed, the difference between the two weights being due to the action of the carbonated water.

All the stones, with the exception of those from Barrabool Hills and Apollo Bay, lost weight. The Darley stone, known to contain a large percentage of carbonate, lost as much as 2 per cent., while the marble lost 1.8 per cent. In the case of the Darley sandstone, one is dealing with a porous stone, where the solution can percolate all through, while with the marble, which has a very low absorption (.18 per cent. by weight) the action is almost entirely confined to the surface. The Darley stone also lost some weight through some of the grains falling away, when the cement was weakened by the solution of the carbonate. The action on the marble was sufficient to remove a film nearly .2 mm. in thickness from the whole surface of the stone, with the exception of the thin carbonaceous veins, which stood out as ridges. The effect on the Apollo Bay stone was to give it a lighter colour, much the same as is produced by a few years' weathering. With regard to the other stones little or no change was noticeable in appearance. The amounts lost by the Sydney, Dunkeld, Stawell and Egerton stones is scarcely appreciable, whereas the marble, Bacchus Marsh and Darley stones all lost considerable amounts, due to the carbonates therein. The increase in weight of the Barrabool Hills and Apollo Bay stones is probably due to the presence of ferrous iron in the stones, which becomes oxidised.

Table of Percentage Losses by Corrosion.

Stone	Weight lost in percentage
Stawell	0.06
Dunkeld	0.01
Barrabool Hills	0.17*
Apollo Bay	0.15*
Bacchus Marsh	0.38
Darley	2.01
Egerton (fine)	0.00
Egerton (coarse)	0.02
Carrara Marble	1.79
Sydney	0.03

* Denotes Percentage gained.

5.—*Resistance to Acids.*

Ordinary city air contains small percentages of hydrochloric, sulphuric, sulphurous, and nitric acids; of these the hydrochloric and sulphuric are the most important.

A solution containing 1 per cent, of each of these acids was made up, and smoothly dressed two-inch cubes, after being dried at 110 degrees C., cooled and weighed, were immersed in 300 ccs. of the solution, each in a separate beaker.

The stones remained thus for a period of fourteen days, with occasional turning over. At the end of this time they were carefully removed, and allowed to drain for some time into the beakers; then, after being rinsed for several hours in a current of water to thoroughly get rid of the acid, they were dried at 110 degrees C., cooled and weighed, and the loss in weight noted.

The solutions were then made up to 500 cc., one portion being used to determine the weight of the dissolved material as chlorides and sulphates, and the other for the chemical analysis of the dissolved material.

During the test some material fell away mechanically, due to the action going on between the matrix of the stone and the acid. This was caught in a filter, ignited, and weighed.

The effect of the acid on several of the stones was most pronounced, especially on those from Barrabool Hills, Apollo Bay, Darley, Sydney and Bacchus Marsh, while little or no change took place in the Stawell, Dunkeld, Egerton and Greendale stones.

The Barrabool Hills stone was bleached to a much lighter colour, and on fracturing the cube the alteration was visible up to about 1.5 cm. below the surface, gradually becoming lighter in colour outwards.

The Apollo Bay stone underwent a very decided change in colour, passing from a bluish-grey in the unaltered part to a tint resembling very closely that of cement on the outside. On fracturing the cube the zone of alteration was seen to be about 1.5 cm. wide, passing from the grey to a rather brown colour, due to the oxidation of the ferrous iron in the stone. From this point outwards there was a gradual loss of colour due to the solution of the iron-containing constituents, up to the cement colour about 1 mm. wide at the surface.

The Sydney stone, on the other hand, gained colour, due no doubt to the oxidation of the ferrous iron it contains, but the colouring was variable. On fracturing the cube it was seen that almost the whole of the stone had undergone an alteration in colour, there remaining a central core about 1 cm. in diameter of unaltered appearance. From this core outwards a beautiful zoning effect was produced, the colour being a deep brown, about 1.5 cm. from the surface, and then fading away to the surface, which in some cases was white and in others varying shades of brown.

The Darley stone was the most seriously affected of all, cracks extending along the bedding planes throughout the whole length of the cube. The cracks were more pronounced at the corners, where some of the material fell away—in fact, the stone required very careful handling to maintain the cubical shape at all. Thin flakes fell away, and a good deal of discolouration was produced by differential iron-staining.

The Bacchus Marsh stone underwent the same changes as the Darley stone, but they were not so pronounced, and little or no cracking was produced in it.

In the table are shown in percentages the total loss the stones underwent, the loss due to mechanical falling away, the loss due to the chemical action of the acids, and the soluble material as oxides, sulphates and chlorides.

During the experiment the CO_2 liberated by the action of the acid on any carbonates present escaped of course.

TABLE OF PERCENTAGE LOSSES IN ACID TEST.

Stone	Total Loss	Mechanical Loss	Loss by chem. action of acids	Sol. material as oxides, sulph'ts and chlorides
Stawell	0.108	0.019	0.089	0.050
Dunkeld	0.283	0.056	0.127	0.094
Barrabool Hills	1.417	0.027	1.390	2.889
Apollo Bay	1.851	0.020	1.831	2.813
Bacchus Marsh	0.792	0.025	0.667	1.225
Darley	1.835			2.337
Egerton (fine)	0.019*	0.015		0.068
Egerton (coarse)	0.027	0.067		0.080
Greendale	0.052*	0.034		0.221
Sydney	1.031	0.038	0.993	1.146

* Denotes gain in Weight.

The percentages of alumina, ferric oxide, magnesia and lime in the dissolved oxides were then calculated from the analyses of the dissolved material, and are as follows :

TABLE OF ANALYSES OF MATERIAL LOST BY CHEMICAL ACTION OF ACIDS.

	Stawell	Dunkeld	Barrabool Hills	Apollo Bay	Bacchus Marsh	Darley	Egerton (fine)	Greendale	Sydney
Alumina (Al_2O_3) -	36.25	16.50	66.25	59.85	24.25	16.00	27.22	31.53	5.20
Ferric Oxide (Fe_2O_3) -	28.13	34.38	31.14	26.65	3.00	25.85	37.10	22.91	83.92
Lime (CaO) - -	24.80	12.80	2.45	7.25	26.67	22.05	20.18	44.67	2.78
Magnesia (MgO) -	10.82	36.32	0.16	6.25	46.08	36.10	15.59	0.89	8.10

An examination of these tables shows that all the stones are more or less attacked by mineral acids, but that in the case of the fine-grained Egerton and Greendale stones there is a slight increase in weight, due probably to the formation of some new salt in the stone. The effect on the Stawell, Dunkeld, Egerton (both fine and coarse) and Greendale stones is very small, the Bacchus Marsh and Sydney stones are acted on considerably, and the Apollo Bay, Barrabool Hills, and Darley stones are affected to the greatest extent.

The mechanical loss is small in all the stones, with the exception of the Darley, but unfortunately a mishap took place with the insoluble portion of this stone, and time did not allow of a repetition of the experiment.

A perusal of the analysis of the dissolved material shows that in the Barrabool Hills and Apollo Bay stones a large percentage is alumina and ferric oxide, the ferrous iron dissolved from these stones being determined in the ferric state. The Barrabool Hills material contains more alumina and ferric oxide, and less lime and magnesia than the Apollo Bay stone.

In the case of the Sydney stone, more than 80 per cent. of the dissolved material is ferric iron, obtained from the solution of ferrous carbonate in the stone, the other three oxides making up the balance with magnesia about 8 per cent. In the case of the Dunkeld and Stawell stones, which are of a different type from the others, the composition of dissolved material is more varied, there being a high percentage of magnesia for the Dunkeld stone and of lime for the Stawell stone.

For the Bacchus Marsh stone the ferric oxide is low, while the magnesia and lime are high, especially the magnesia, these two oxides being present in carbonates in the stone.

The Darley material is high in lime and magnesia, and low in alumina. The material dissolved from the Egerton and Greendale stones is much the same in composition, with the exception that the Greendale analysis shows a high lime and very low magnesia percentage, whereas in the Egerton material these two oxides are well distributed.

6.—*Microscopical Examination.*

Stawell Stone.

Examined under the microscope in thin section, this stone is seen to be made up almost entirely of rounded quartz grains, which are very closely packed together, so that there is a minimum amount of cementing material. A great number of the quartz grains contain numerous needles of rutile, while most of them have apatite, zircon, or small liquid inclusions, so that the sand grains are very probably of granitic origin. These quartz grains are of uniform size, and in nearly every case well rounded, showing that they have undergone a good deal of attrition before being cemented together. There are a few subangular, but almost no angular grains. A very occasional crystal of a light brown pleochroic mineral with a high refractive index is seen, and is probably the mineral sphene. The binding material is in parts seen to be secondary silica, while in other parts it is felspathic. Only occasionally do there occur patches of cement of any size, but the cementing together of a number of small quartz grains by secondary silica is very common. In the hand specimen numerous patches and bands of what are termed "flints" occur. On sectioning these it is seen that they are nothing more than a number of grains cemented by secondary silica and are of secondary origin in the stone.

The average size of the grains is about .25 mm., and from a microscopical examination the sandstone appears to be almost the ideal one for weathering. (See Plate I., Fig. 1.)

Dunkeld Stone.

This is made up almost entirely of sand grains, but differs from the Stawell stone in that the grains are much smaller, and of a more angular character, also they are not so much compacted, with the result that there is a great deal more binding material.

This cementing material is uniformly stained with iron oxide, which gives it a light brown colour. It is the presence of a fair amount of this fine-grained matrix and the almost total absence of patches of secondary silica that renders this stone cheaper than the Stawell stone to work. (See Plate I., Fig. 2.)

Barrabool Hills Stone.

It is at once seen that this stone is of an entirely different nature from the Stawell and Dunkeld stones, and appears to be made up of reassorted igneous materials, most of which have been altered. Angular crystals of quartz are scattered through the rock, while a good deal of both orthoclase and plagioclase is present. Most of the felspars are kaolinised, and form part of the cementing matrix of the stone. The quartz and felspar fragments are set in a fine-grained matrix made up of chlorite, haematite, mica and volcanic fragments. The minerals in the rock are considerably altered, and this no doubt accounts for its low crushing strength. (See Plate II., Fig. 1.)

Apollo Bay Stone.

The description of the Barrabool Hills stone may be taken as that of this stone, with the exception that this is much fresher, and small grains of magnetite occur here and there through it. An examination of sections made from the freshly quarried stone, and of some which had been exposed for about fifteen years, showed that there was little or no difference, so that the stone appears to have good weathering properties. (See Plate II., Fig. 2.)

Bacchus Marsh Stone.

It was a matter of some difficulty to obtain a thin section of this stone for microscopical examination, owing to its weak binding properties. The stone is made up of fine grains of angular quartz set in a fine-grained matrix of argillaceous material stained brown by ferric oxide. Occasional crystals of mica and felspar occur through the section, but the stone is almost entirely made up of sand grains, and a fine-grained matrix. The proportion of grains to matrix is far too small to allow of a good weathering stone, as the cementing matrix is of an argillaceous character, and so a poor binding material; thus from microscopical evidence one would conclude the stone to have a low crushing strength, and to have very little weather-resisting properties. (See Plate III., Fig. 1.)

Darley Stone.

This stone resembles closely that from Bacchus Marsh, but contains more fine-grained matrix, and in addition carbonates are present. The grains of quartz are small and angular, and well separated from one another. From the amount and argillaceous nature of the matrix, together with the presence of carbonates, one would consider the stone to have poor weathering properties, and to have a low crushing strength. (See Plate III., Fig. 2.)

Egerton Stone.

Fine-grained.—This is made up of very fine grains of quartz, set in a matrix of argillaceous material. The quartz grains are subangular, and of fairly even size. There is a fair percentage of fine-grained matrix, which is evenly distributed, and does not occur in large isolated patches. This stone is much superior to the Bacchus Marsh and Darley stones, from a microscopical point of view, and indicates good weathering properties, along with a fairly high crushing strength. (See Plate IV., Fig. 1.)

Coarse-grained.—This stone is of the same nature as the fine-grained one, but has a much coarser grain, and a good deal more argillaceous material all through it. The grains are angular, very uneven in size, .7 mm. to .07 mm. in diameter, and large isolated patches of the fine-grained matrix occur. This matrix is present to the extent of about 25 per cent., and patches 1 mm. in diameter occur. The microscopic characters indicate only fair weathering properties, and a low crushing strength.

Greendale Stone.

This has much the same microscopic character as the coarse-grained Egerton stone, but in addition has scattered through it specks of ferric oxide, which give the stone a light brown colour. (See Plate IV., Fig. 2.)

CHEMICAL ANALYSIS.

Chemical analyses were carried out by the author on all the sandstones, with the exception of the Stawell stone. The analysis of that stone in the following list was made by the Victorian Mines Department.[1]

In all cases samples for analysis were taken from material uniform with that used for the other tests. For stones of aqueous origin like these sandstones a chemical analysis does not carry so much weight as for igneous rocks, because in the former uniformity in either chemical or physical characters of even closely adjacent beds is not to be relied upon, whereas in igneous rocks which have cooled from a molten magma, uniformity of composition is much more likely. However, chemical analyses of these stones, while only holding for the particular beds of which they are samples, serve to indicate in general the composition of the stones, and what constituents are liable to alteration during weathering; this information used in conjunction with the other tests is often of great value.

The Stawell Stone is seen to be a very highly siliceous one, and to be made up almost entirely of silica in the form of sand grains. The combined water, alumina, and a certain amount of

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[1] Ann. Report Sec. for Mines, Victoria, 1907, p. 63.

the silica occur in the small amount of cementing material in the stone. The iron oxides, magnesia, lime and alkalies are present to only a slight extent, while carbonates are altogether absent.

The Dunkeld is a little lower in silica than the Stawell stone, but it contains more combined water and alumina, owing to its larger percentage of cementing material, the alkalies are a little higher, but not present to any appreciable extent, while the iron oxides and alkaline earths are very low.

In neither of these stones does there appear to be any constituent easily affected chemically, under ordinary weathering conditions.

The Barrabool Hills and Apollo Bay Stones, from their chemical analyses alone, are seen to be different types of stones from the others, and a very close resemblance exists between the chemical constitution of these two, also a comparison of their analyses with those of the Victorian Dacitès shows marked similarities. The silica is low, while the alumina, combined water, and alkalies are high.

The ferrous oxide in the Apollo Bay stone is about twice that of the Barrabool Hills stone, also the former has a lower ferric oxide value than the latter. It is the relative amount of these two iron oxides which governs the colour of the stone, the more ferrous oxide the greyer the stone, the brown colour of the Barrabool Hills stone being due to the ferric nature of the iron it contains.

A small portion of the fresh grey Barrabool Hills stone was analysed for ferrous iron, and gave 3.70 per cent., while an adjoining piece of brown stone gave only 1.80 per cent. The presence of the ferrous oxide in the stone must be regarded as a defect, as it is so readily oxidised on weathering.

The Bacchus Marsh Stone is only moderately high in silica for a sandstone, while the combined water and alumina are high, but this is a natural result of the large amount of argillaceous material the stone contains. The ferric iron value is high, and accounts for the brown colour of the stone, while the alkalies occur in the small amount of felspathic material the stone contains. Carbòn dioxide occurs to the extent of .32 per cent., and is combined partly with the lime and partly with the magnesia. The presence of this material is detrimental, as it is readily removed under ordinary weathering conditions, thus weakening the stone.

The Darley has much the same composition as the Bacchus Marsh stone, but has less argillaceous material, and considerably more carbonates, the 1.82 per cent. of carbon dioxide is high, and occurring in a stone of weak physical features like this one is alone sufficient to condemn it for city structures. Manganous oxide occurs to the extent of .20 per cent., and in the form of manganese carbonate appears as the pink staining which the stone shows irregularly through it.

The Egerton and Greendale stones are similar to one another in composition, and are fairly high in silica. They contain a fair amount of argillaceous material, but there is nothing in either of the stones which is liable to chemical removal or alteration to any extent under normal weathering conditions.

TABLE OF CHEMICAL ANALYSES.

	Stawell	Dunkeld	Barrabool Hills	Apollo Bay	Bacchus Marsh	Darley	Egerton	Greendale
Silica (SiO_2) - -	96.19	90.49	64.13	64.00	77.69	83.15	90.22	86.37
Alumina (Al_2O_3) -	1.90	5.66	18.59	15.88	10.00	5.48	7.56	7.29
Ferric Oxide (Fe_2O_3)	0.37	0.59	1.99	1.90	2.70	1.57	tr.	1.67
Ferrous Oxide (FeO) -	0.06	nil	1.78	3.86	tr.	nil	nil	nil
Magnesia (MgO) -	0.09	tr.	1.24	1.81	0.96	0.64	tr.	0.43
Lime (CaO) - -	tr.	0.27	1.34	2.02	0.74	2.90	tr.	tr.
Soda (Na_2O) - -	0.04	0.88	4.36	3.42	1.02	0.56	0.38	0.84
Potash (K_2O) - -	0.39	0.46	1.98	1.86	1.74	0.24	0.22	0.34
Free Water ($-H_2O$) -	0.11	0.20	1.38	1.04	1.56	0.46	0.58	0.10
Combn'd. ,, ($+H_2O$) -	0.48	0.97	3.43	3.84	3.02	2.51	1.56	2.50
Carbon Dioxide (CO_2)	nil	nil	sl. tr.	nil	0.32	1.82	nil	nil
Mang. Oxide (MnO) -	—	nil	str. tr.	str. tr.	tr.	0.20	tr.	tr.
Titanium Oxide (TiO_2)	0.10	—	—	—	—	—	—	—
Total -	99.73	99.52	100.22	99.63	99.75	99.53	100.52	99.54

GENERAL SUMMARY OF RESULTS.

Stawell Stone.—This has excellent weathering properties, as shown by its low absorption, great resistance to corrosion by carbon dioxide, and to the action of mineral acids. It has a very high crushing strength, and is an expensive stone to dress. Chemically the stone is very stable, and microscopically appears almost the ideal weathering sandstone. The objections which may be raised to the stone are its cost of dressing due to the initial hardness and the "flints," the presence of current bedding, and its cold appearance. On the other hand, it is the best weathering sandstone in Victoria, and blocks of any reasonable size may be obtained, so that for public buildings it is an eminently suitable one.

Dunkeld Stone.—This has excellent weather resisting properties, on account of its low absorption, its resistance to carbon dioxide and the mineral acids. Its crushing strength is only fair, but it is considerably cheaper than Stawell stone to dress. A grave objection to this stone is its appearance on weathering, due to the very frequent current bedding, to the differential iron-staining, and to the pitting along the bedding planes, owing to the falling out of fine powdery material originally present. It must be regarded as only a second-class stone.

Barrabool Hills Stone.—This has a very high absorption, and, while resistant to the effect of carbon dioxide, is readily affected to a large extent by mineral acids. It is light, has a low-crushing strength, and is easily dressed. An examination of the buildings of this stone, together with the results of the above tests, indicates that the stone is only a fair one, and that when used in rough dressed blocks of small size gives the best results.

Apollo Bay Stone.—This is fairly compact, has a medium absorption, is very resistant to carbon dioxide, but readily acted on by mineral acids. It has a good crushing strength, and works both freely and well. Objections may be urged against the colour, especially after weathering for some time, and to the action of acids on it; but in virtue of its absorption, its dressing properties, and its known weathering properties it must be set down as a much better stone than that from the Barrabool Hills and as a good stone.

Bacchus Marsh Stone.—This is not at all a durable stone, on account of its physical and chemical characters. It is light, and has a low crushing strength due to the poor adherence of its particles. Owing to its chemical constitution it is attacked and weakened by the action of carbon dioxide, and especially by the mineral acids. It has a very high absorption, and from the durability of the stone, as seen in Bacchus Marsh and Melbourne, cannot be regarded as other than a poor stone.

Darley Stone.—This is poor, both physically and chemically, as a building stone. It is light, very porous and has an exceedingly low crushing strength. It yields to the attack of carbon dioxide and the mineral acids very readily, owing largely to the carbonates it contains. It is interesting to note that at one time this stone was chosen for the Houses of Parliament, but from the results obtained above, and an examination of the stone in Melbourne structures, it must be considered a very poor stone for building purposes, especially in the city.

Egerton Stone (*Fine-grained.*)—This has a fair crushing strength, is rather absorptive, but very resistant to carbon dioxide, and the mineral acids. It has the advantage of being light, dressing easily and well, and from what is known of its weathering properties in the field should be a good, durable stone if precautions are adopted to keep it as dry as possible. The stone has not been used to any extent, but if the quarry opens up favourably, as it promises to do, it should fill the long-felt want of a durable stone with cheap dressing qualities.

Coarse-grained.—This is physically weaker than the fine-grained material, but is chemically stable. It dresses easily, and although inferior to the former one, should, with the same precautions, prove a good serviceable stone.

Greendale Stone.—This has much the same qualities as the coarse-grained Egerton material. It is light, has a low crushing strength, is rather absorptive, but very resistant to the action of carbon dioxide and the mineral acids. No opportunity of judging this stone in the field has been obtained, but from the laboratory results it should, if kept reasonably dry, prove a good serviceable stone.

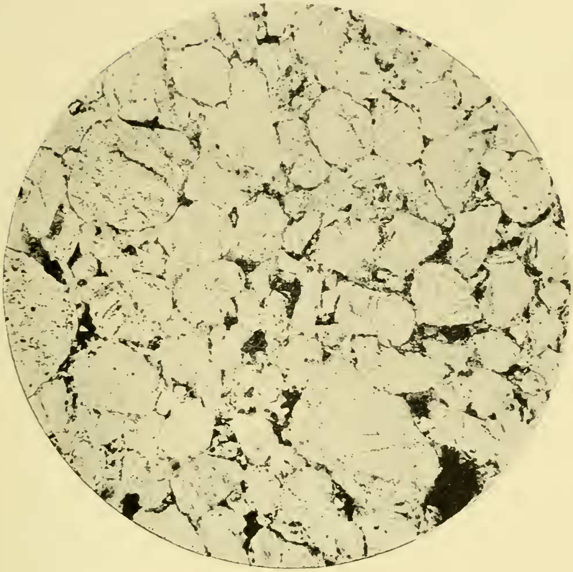

Fig. 1

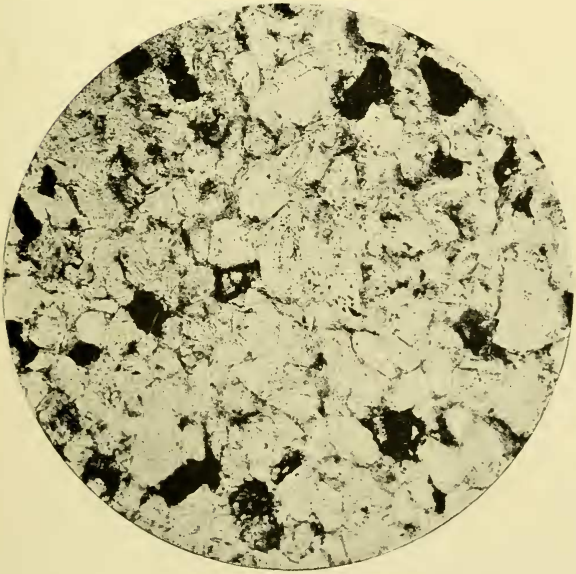

Fig. 2